Labor. Analysis of labor issues has a long history at the WZB. The Project Group on Globalization, Work, and Production focuses on questions arising from changing divisions of labor in a global economy and on aspects of working conditions, employee relations, and the design of personnel and production systems in automotive industries in the BRIC states. Issues of work, gender, and family are explored primarily in the Research Area on Education, Work, and Life Chances and in the President's project group.

The Fourth Revolution: The Transformation of Manufacturing Work in the Age of Digitalization

Martin Krzywdzinski, Ulrich Jürgens and Sabine Pfeiffer

Summary: German government and companies claim the beginning of a fourth industrial revolution, based on the internet of things and a new generation of flexible robots and assistance systems. Industrie 4.0 has thus far only existed in model factories. The development bears risks (job losses, devaluation of skills, increasing surveillance of employees) as well as opportunities (increasing importance of the human factor and improvement in ergonomics in manufacturing). Social research needs a long-term perspective in analyzing the experiences with the new technologies and their institutional conditions, and to show possibilities of a human-centered design of production processes.

Current discussions suggest that manufacturing is about to experience a massive transformation. To leave no doubt about the significance of the impending changes and to shake the relevant actors out of their sleep, the German federal government has officially referred to this process as the fourth industrial revolution, following the mechanization of production using steam power in the late eighteenth century, electrification and the emergence of assembly line production in the late nineteenth century, and the digital revolution based on microelectronics in the late twentieth century. Hence the term "Industrie 4.0."

What exactly is so new about this new industrial revolution, especially since the 3.0 revolution took place not so long ago? What do the new technologies mean for the future of work in industrial production?

One core element of Industrie 4.0 is the use of "cyber-physical systems." According to work scientist Dieter Spath, these systems are "autonomously controlled physical entities [i.e., machines but also individual components] that make decentralized decisions, communicating with each other in an internet of data and services." A second key feature is the emergence of flexible robots that are now capable of interacting directly with human workers—the robots are leaving their cages, as it were. And finally, the use of assistance systems such as data eyeglasses and smart watches is considered essential for the new era, because such systems can support workers by providing them with digitalized knowledge when and where they need it.

A roadmap for revolution?

These technologies offer diverse opportunities to fundamentally change workplace structures and processes. This opens up vast possibilities for redesigning manufacturing work. While there is far-reaching potential for automation, the new technologies also involve enhanced opportunities to support workers and

to strengthen their capacity for autonomous action and decentralized self-regulation.

We do not know at this point how these possibilities for reshaping manufacturing work will eventually be implemented and whether companies will introduce the new technologies in a gradual or disruptive manner. The answers to these questions depend on what the relevant actors will do and which of the chosen approaches will prove most successful in the market. The development of Industrie 4.0 is still in its early stages, and there are few examples of how to apply the new tools outside of laboratories and model factories. Accordingly, the discussion is marked by many uncertainties and quite a few absurdities—for instance when practitioner workshops produce roadmaps (i.e., plans to orchestrate the sequence of events and align the related activities) for what will supposedly be a revolutionary transformation.

Despite repeated assertions that the technologies are now ready for application, it is uncertain how they will work in a real-world production setting. Based on past experiences with automation processes, the degree of process stability produced under laboratory conditions is hardly ever achieved in practice. The multiplicity of possible disruptions caused by broken parts (or parts that do not exactly meet the specifications), machine breakdowns, or employee mistakes creates a very high need for improvisation and creative problem-solving—in complex as well as simple production processes. Industrial sociologist Ulf Ortmann, for example, wrote about the practical problems experienced by a textile factory in its attempt to self-regulate commodity flows with the help of RFID tags (transponders for the wireless localization and identification of objects) sewn into or glued to garments. Since many tags turned out to be broken or could not be read, workers had to go through the "nerve-racking routine" of checking all garments to find out whether the machines had identified them correctly.

Even if such problems are the inevitable teething troubles of new technologies, we do have to ask about the future role that human workers will play in the operations layout.

Existing studies on the future of manufacturing work in the context of Industrie 4.0 identify risks as well as opportunities, expecting that there will be winners and losers among employees. Let's begin with the risks. Human work could be replaced by machines, meaning that jobs would be lost. One recent study that caused quite a stir was that by Carl Benedikt Frey and Michael Osborne, who looked at the US labor market in 2013 and found that 47 percent of the workforce are employed in occupations that are very likely to be replaced by automation in a decade or two. The potential for computerization is assumed to be much higher for industrial occupations: 81 percent for mechatronics technicians, 84 percent for toolmakers, and 97 percent for assemblers. Authors at the Center for European Economic Research (ZEW), in a brief report to the German Federal Ministry of Labor and Social Affairs, applied the Frey/Osborne method to the German labor market, estimating that 42 percent of the workforce are endangered. However, the ZEW authors point out that such predictions become more realistic if we look at the potential for automation at the level of individual work tasks rather than entire occupations. Using that approach, it turns out that only about 12 percent (9 in the US) of all tasks have a high likelihood of being performed by computers and software in the medium term. No separate assessment was made for manufacturing jobs. Yet both the occupation-based and the task-based predictions about the impact of Industrie 4.0 on employment are based on sometimes questionable assumptions and anything but robust statistical raw data. In other words, we are still a long way from making reliable predictions.

A second risk involves the possible devaluation of qualifications and skills. After the third industrial revolution, the application of new technologies often resulted in a polarization of job requirements, primarily among the group of workers with medium-level qualifications. The skilled welder, for example, was on the one hand replaced by the operator of an automated welding machine, on the other hand by the unskilled worker inserting parts into the machine, also known

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in Germany as Restarbeiter (worker performing residual work). With the advent of Industrie 4.0, we can expect such residual work to become obsolete for the most part; at the same time, higher-skilled tasks, and increasingly also the indirect tasks performed by skilled workers and engineers, can be made easier, for instance with the help of assistance systems guiding workers by sending them instructions via smart watches or data eyeglasses. Thus the use of digital assistance systems involves the danger of devaluating experiential knowledge even among workers previously considered highly skilled.

The scope of human decision-making can be restricted substantially by using 4.0 technologies. This also implies restrictions on the opportunities for workers to learn and develop. Finally, the list of potential risks also includes new possibilities for performance monitoring and surveillance. Digital assistance systems such as tablets, smart watches, or data eyeglasses continuously generate data about an employee's location, the speed at which they perform their tasks, and the quality of their results; employee-related data about their performance, fitness, and motivation become a source for big data.

Aside from the risks, however, there are also a number of opportunities. First of all, the possibilities for ergonomic workplace design will improve. In fact, workplace ergonomics is a key field for win-win solutions when implementing Industrie 4.0 concepts. Assistance systems and the use of robots enable specific solutions for problematic ergonomic situations and the creation of better workplaces for employees with health restrictions. In addition to making work more human, this area also provides opportunities for addressing the ageing workforce issue and the employment of workers with impaired productivity. As a legacy of the second industrial revolution, today's manufacturing sector continues to feature a wide range of ergonomically problematic workplaces (called "red" workplaces in industry jargon).

Another opportunity is the possible upgrading of jobs in manufacturing and the potential skills gains of workers on the shop floor. Process support provided by mobile robots and assistance systems can be used to strengthen the team's operational autonomy, to facilitate training processes, and to make improvements. Especially for assembly line workers, use of the new technologies could mean a liberation from repetitive and monotonous work in favor of tasks involving process monitoring and improvement. Such a development, however, would require a shift away from today's predominant philosophy of lean production—a philosophy whose global triumph was celebrated as another industrial revolution not so long ago, and which has resulted in a return to design principles of standardized and short-cycle work.

Whether the future will be shaped more by the risks or more by the opportunities will depend to large extent on the implementation concepts that will become predominant in practice. It would be unfortunate if the opportunities of Industrie 4.0 were to be narrowed down to automation goals at the expense of solutions that might strengthen manufacturing workers' ability to act and the self-regulation of teams. As research has shown, the use of complex digital manufacturing technologies increases the importance of experiential knowledge. It is true that imponderables occur less frequently in highly automated processes, but if they do occur, it is all the more important to take the right actions. Those actions have to be performed under time pressure and require the ability to act without having clear information.

Progressive digitalization requires workers to master complexity on a daily basis, to handle imponderables in a confident manner, and to take the right actions in situations that cannot be planned. Sabine Pfeiffer and Anne Suphan have shown that, across all industries and qualification levels, 71 percent of the German workforce have to deal a lot with imponderables, complexity, and change. At the top of the list are occupations that are particularly relevant for Industrie 4.0, such as the core IT occupations, industrial mechanics, and toolmakers.

The distribution of risks and opportunities is not determined by technology. The abovementioned Industrie 4.0 technologies offer a particularly strong degree of

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freedom when it comes to implementation. The current development, therefore, could also serve to strengthen co-determination, because in Germany the use of new technologies that affect the workplace often has to be approved by the works councils. It is no coincidence that the industrial unions are making substantial efforts to prepare works council members and the unions' ombudspersons inside the companies for this new topic. What will matter most with regard to the influence of co-determination, however, will be the extent to which workers and their representatives will get involved in the implementation of the new technologies in their companies.

Finally, the issue of risks and opportunities also touches upon the future competitiveness of Germany as an industrial location. The first industrial revolution represented the birth of industry as a new mode of production and a new organizational field. The fourth industrial revolution will no longer be driven by traditional industrial enterprises but essentially by IT companies. The strongest players in the IT industry are not based in Germany, hence the fourth industrial revolution could challenge Germany's industrial basis.

As a consequence, the issue of risks and opportunities associated with the new technologies will also rekindle the debate about advantages and disadvantages of national institutional arrangements. In Germany, the training of skilled workers is considered a key advantage with regard to Industrie 4.0. In the United States, by contrast, the opportunities are seen more in the possibility of simplifying skills requirements and training semi-skilled workers with the help of technology.

For social scientists, all of this implies a strong need for research; at the same time, they too are faced with the problem of having to deal with uncertainty. Predictions concerning the effects of the new technologies (as the experiences with earlier discussions about the effects of microelectronics have shown) are little more than speculation at this point. Now is the time to indicate ways to actively shape this development, and hence to influence the distribution of risks and opportunities as the new technologies are beginning to be applied. This can be done by analyzing the practical experiences with the new technologies at the workplace, by collecting data about the spectrum of different approaches and their social and institutional success factors and cumulative effects, and by highlighting the full range of possible actions. One thing is certain: This kind of research will require a long-term perspective, as industrial revolutions do not happen overnight.

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